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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

THE STRUCTURE

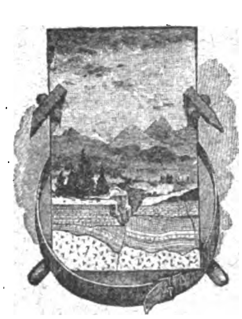
OF THE

TRIASSIC FORMATION OF THE CONNECTICUT VALLEY

BY

WILLIAM MORRIS DAVIS

EXTRACT FROM THE SEVENTH ANNUAL REPORT OF THE DIRECTOR, 1885-1886



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TRIASSIC FORMATION OF THE CONNECTICUT VALLEY.

By William Morris Davis.

The physical history of the Triassic formation of the Connecticut Valley may be considered under three heads: First, the conditions of its accumulation; second, the structure that it now possesses; and, third, the mechanical disturbance by which the present structure has been produced.

I. THE CONDITIONS OF ACCUMULATION.

ORIGINAL AREA OF DEPOSIT.

The Triassic strata rest unconformably on steeply upturned schists and gneisses. It may therefore be supposed that an old land of crystalline rocks, long exposed to denudation, was for a time and in part submerged, and that the body of water thus formed became the seat of deposition of the waste brought from the area that remained uncovered. The present extent of the formation measures about ninety-five miles north and south, from Long Island Sound, where it runs under the sea, nearly to the northern boundary of Massachusetts, and from fifteen to eighteen miles east and west in central Connecticut and southern Massachusetts, where it is broadest. The original area was greater than this, as there has been demonstrable loss by marginal erosion, but it is generally thought that the loss has not been very great.

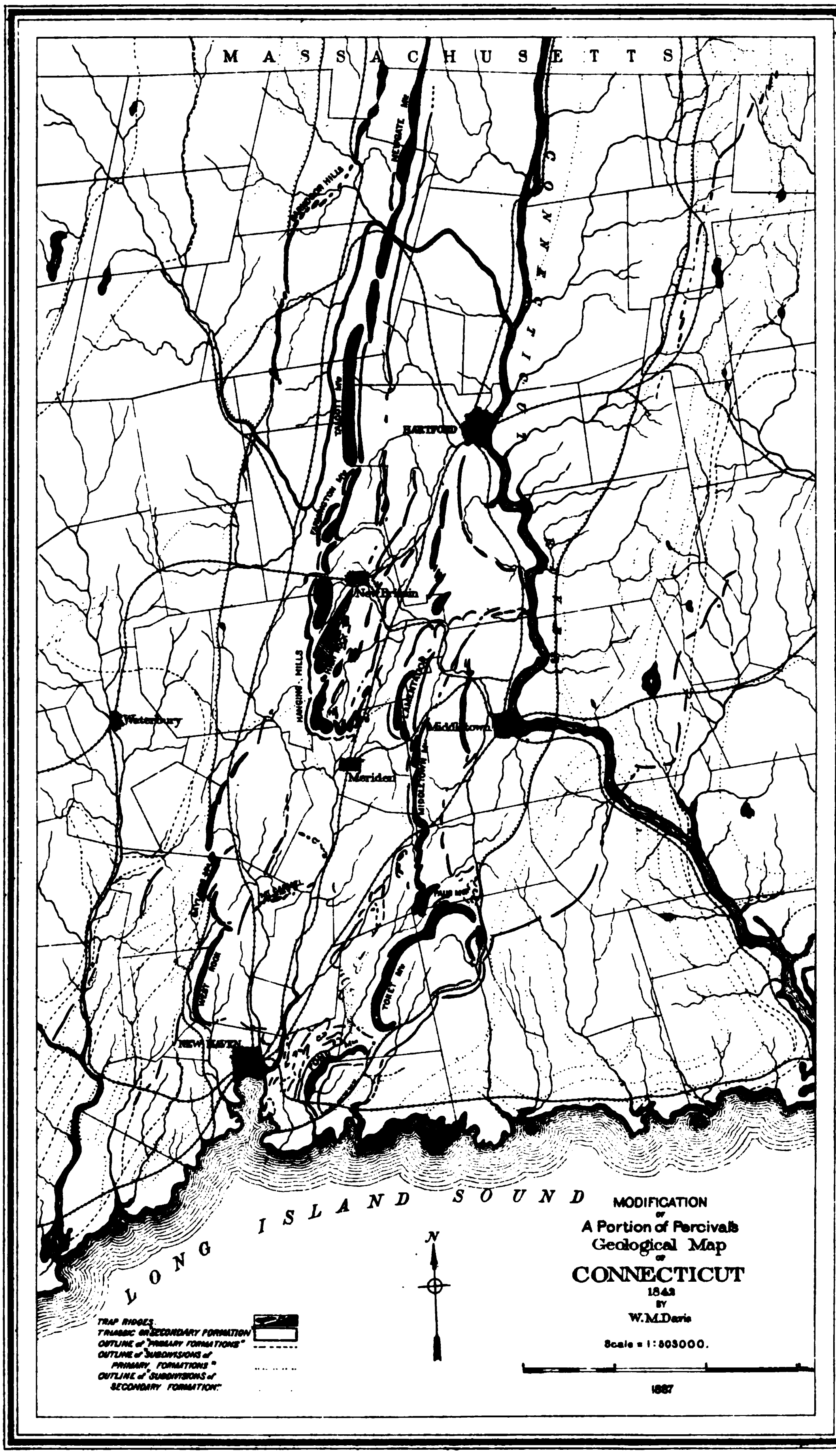
We are not, however, confined to this conclusion by a very strong line of argument. The rapid change from finer sandstones and shales that generally appear in the central parts of the formation to the coarse sandstones and conglomerates that characterize the margin is usually cited as implying a narrow limitation of the area of deposit; but it is not yet demonstrated that the finer central strata are the equivalents of the coarser marginal layers; the latter may mark localities on the advancing shore during submergence that were favorable to the formation of coarse deposits, while the former may correspond to a later date of more general submergence; moreover, in some cases the finer shales approach close to the present margin of

the formation. No isolated outliers of the formation have yet been discovered, unless the little Southbury-Woodbury area in western Connecticut be so regarded, but the region around the area that is still covered by the Triassic rocks has been elevated to an altitude and during a time sufficient to have suffered much loss by Post-Triassic erosion. The general freedom of the same surrounding region from the igneous rocks so closely associated with the Triassic formation in its various areas along the Atlantic slope may also suggest its escape from Triassic submergence; but in our present state of knowledge concerning the cause of this peculiar association it can hardly be employed in this argument. It therefore does not seem impossible that the original Triassic area may have been much larger than the present; but the burden of proof lies clearly on those who would contend for what now appears to be so far beyond the necessities of the case.

The only notably peculiar conditions attendant on the period of deposition were those connected with the intrusion and eruption of broad sheets of igneous rock. We do not here find great masses of breccia, as in the Mesozoic of Pennsylvania, or heavy beds of exceptionally coarse conglomerate, as in the same formation in Virginia, which require unusually active or powerful processes in their accumulation. Very coarse conglomerates, with bowlders from two to four feet in diameter, are known in few localities in the Connecticut Valley, and these are in all cases close to a possible shore of derivation. The deposition of the aqueous rocks may therefore be in general described as rather commonplace, presenting the ordinary variety of conglomerates, sandstones, and shales; they are mostly of a red or brown color, but the shales are sometimes dark and bituminous, with impressions of fish and of land plants; occasional thin seams of coal have been reported and a small but significant bed of impure, grayish limestone makes its appearance among the shales. The little that is known of the sequence of these rocks will be stated below.

IGNEOUS ROCKS.

There is a more special interest connected with the occurrence of the igneous rocks that constitute so characteristic a part of the formation. They are generally described as dolerites or diabases, but, as lithological questions do not enter into this report, they will here be called by the old indefinite name of "trap," which is at present significant enough in considering their physical history. They occur as dikes, breaking across the sedimentary beds; as intruded sheets, driven between the beds and closely conformable to them; and as contemporaneous overflows, lying upon the beds that had been formed at the time of their eruption and buried under the later deposits. The distribution of the trap rocks was carefully worked out in Connecticut by Percival and illustrated with much accuracy in his remark-


MASSACHUSETTS
CONNECTICUT
HARTFORD
New Britain
Middletown
Meriden
Waterbury
NEW HAVEN
HANGING HILLS
TALCOTT Mt.
LONG ISLAND SOUND
N
MODIFICATION
OF
A Portion of Percivals
Geological Map
OF
CONNECTICUT
1842
BY
W. M. Davis
Scale = 1:803000.
1887
TRAP RIDGES.
TRIASSIC OR SECONDARY FORMATION
OUTLINE of "PRIMARY FORMATIONS"
OUTLINE of "SUBDIVISIONS of PRIMARY FORMATIONS"
OUTLINE of "SUBDIVISIONS of SECONDARY FORMATION"

able geological map of that State published in his Geology of Connecticut, 1842, and here in part reproduced as Plate LII; but he gave little attention to the structural differences between dikes and sheets. The middle part of the map is here represented, to show the Triassic district between the adjacent crystalline areas and the trap ridges within the Triassic area. The township names and the lines of water-parting given by Percival are omitted, and the railroads and several names are added. The dotted and broken lines in the crystalline areas show the strike of the schists; the trap ridges are dotted within their boundary lines. The various letters and numbers refer to the text of Percival's report. Attention is called to the general parallelism between the oblique structural lines in the neighborhood of the Hanging Hills and the strike of the schists shown in the northeastern and southwestern corners of the map.

Hitchcock mapped the trap ridges in Massachusetts for his report on that State, published in 1841;[1] he gave little attention to their distribution and to the topographic form that they determine, but recognized the contemporaneous origin of the overflows.

Dikes.—The dikes do not present any peculiar or important features, as yet observed; they are variable in thickness and attitude and no system has been found in their distribution; they are probably to be regarded as lines of supply for the intrusions and overflows.

Intrusive sheets.—The intrusive trap sheets occur, as far as now determined, only along the western border of the southern half of the formation, and do not extend into Massachusetts. They are known by their generally compact texture and by the induration they have caused in the overlying sandstone. East Rock, a conspicuous bluff north of New Haven, is the southernmost member of this series. West Rock, and the long, broken ridge running northward between the towns of Hamden and Bethany, and Cheshire and Prospect, are most likely of the same intrusive origin, but this region has not been fully explored. Southington, Bristol, and Farmington have no representative of this sheet, but a broken ridge, similar to the one above named, appears in Avon and extends across Simsbury and Granby, beyond which it has not been recognized. The proof of intrusion of this northern member is not complete, as no contacts with the overlying sandstone have yet been found; but, where it was examined about the Barn-door Hills of Granby, the eastward slopes present nothing of the scoriaceous texture that ordinarily characterizes the upper surface of overflows. The smaller ridges near the Quinipiack and Farm Rivers have not yet been sufficiently studied for description here.

The numerous interruptions in the ridges formed by these trap outcrops might be regarded as indicating so many independent intrusions and the curvature of the ridges might mean that the sheets

[1] The map was published in 1844.

were intruded after the bending of the adjacent strata by which they were guided; but an explanation more consonant with that demanded by the structure of other parts of the formation contradicts this view and suggests that the several ridges above named are parts of only one or two large continuous sheets that were intruded while the sedimentary beds were still horizontal and that afterward suffered dislocation at a time when the whole formation was disturbed. The evidence for this will be presented under the next general head, but it may be now briefly stated that intrusive sheets are well known elsewhere among horizontal beds in which they have produced very little disorder, so that the supposition here made is entirely admissible on general principles; that the relative attitude of the several members of the intrusive ridges is closely imitated in that of the ridges formed by the overflow sheets, whose dislocation must have been the result of subsequent external force; and, finally, that the relative positions of the ridges formed by the intrusive and the overflow sheets are such as very strongly to suggest a single control in their determination.

Overflow sheets.—The trap sheets formed by contemporaneous eruption and overflow are on many accounts the most important members of the formation. They are recognized by the scoriaceous texture of their upper surfaces, by the absence of induration from baking in the overlying sandstones, by the occurrence of sediments filling the little amygdaloidal cavities in the upper surface of the sheet, and by the presence of fragments of trap, often more or less water-worn, in the next overlying beds. The discovery of these several indications is a matter of difficulty, owing to the heavy covering of drift that so generally obscures the desired lines of contact, but they have been found at a sufficient number of localities to leave little doubt in the matter. Beginning at the southern end of the formation, we find that fragments of trap occur in the overlying sandstone at the north end of Pond Mountain, and the upper surface of the sheet making this ridge is very scoriaceous where it is exposed, for two miles along the western side of Saltonstall Pond. The same may be said of several localities on the eastern slope of Toket Mountain; contacts were found at two points on this sheet showing the amygdaloidal cavities of the trap surface neatly filled with fine, sandy sediment. The north end of Lamentation Mountain, south of Berlin village, is cut across by a small stream, disclosing similar contacts and inclosures. The upper surface of the trap sheet that forms the picturesque Hanging Hills, northwest of Meriden, is highly vesicular over large spaces. Mt. Tom, in Massachusetts, is overlaid with a sandstone in which trap fragments have been found. The sheet of trap that caps Deerfield Mountain farther north is covered by a sandstone giving the same evidence. All these are therefore considered overflows. Thin sections of specimens taken from the last two lo-

calities were studied some years ago by Prof. B. K. Emerson, of Amherst College,[1] and a series of specimens from the other localities have lately been submitted to Mr. J. E. Wolff, of the U. S. Geological Survey, for preliminary examination. Microscopic observation thus gained confirms the evidence gathered in the field.

The above localities represent different points in the series of high trap ridges or mountains that extend, with more or less interruption, from Long Island Sound through the whole length of the formation. The smaller trap ridges that accompany these mountains must also be considered contemporaneous overflows, as far as their character is determined at all. They were called "anterior" and "posterior" ridges by Percival, according as they stand to the west or to the east of the main ridges, and these terms may properly be continued, as they are now seen to indicate relative age as well as attitude. The anterior trap is so vesicular on its upper surface that its outcrop is commonly described by Percival as an "amygdaloidal ridge." Well exposed contacts of its trap with the overlying sandstones have been found as yet only in the gorge of the Farmington River at Tariffville and in a railroad cutting at the same village, Prof. W. North Rice, of Wesleyan University, having pointed out these excellent localities. The upper part of the trap is vesicular, with an irregular surface, and the adjacent sandstone contains numerous water-worn pebbles of trap. The rocks near to the anterior ridge at the north end of Toket Mountain furnished sections that were considered by Mr. Wolff to contain small water-worn fragments of trap. The posterior ridges are better exposed. The two members posterior to Pond Mountain gave good evidence of their character; the eastern of the two is covered by a deposit largely composed of trap waste, and the western is associated at its northern end with a heavy conglomerate in which trap bowlders, up to four feet in diameter, are found. The ridge posterior to Toket Mountain is at one point called a dike by Percival, but the only reason for this seems to be its steep inclination. It is closely conformable to the strike and dip of the adjoining sandstones and conglomerates, but no contacts with them were found. The posterior ridge that crosses the Aramamit River at Rock Falls, a few miles southwest of Middletown, is covered by a shaly sandstone inclosing trap pebbles, one of which, lying about six inches over the highly vesicular surface of the trap, was beautifully water-worn. The ridge apparently posterior to Mt. Tom, on the Connecticut River, well exposed in a quarry by the railroad three miles north of Holyoke, Mass., is covered by a sandstone containing plentiful fragments of trap. Other localities giving equally decisive evidence will doubtless be found.

It thus appears that a good number of the many large and small

[1]Am. Jour. Sci., 3d series, vol. 24, 1882, pp. 195, 270, 349.

trap ridges in the central and eastern part of the formation are the outcropping edges of overflow sheets. Many ridges remain to be examined to discover if they give independent evidence of a similar origin, but meantime there are two good reasons for anticipating the results of such investigation. First, if this closely associated series of ridges contained both intrusions and overflows it would be difficult to explain why the contacts thus far discovered should give evidence for overflows only, especially when it is remembered that the indurated sandstone on the back of a dense intrusion is much less easily worn down than the unbaked sandstone on the vesicular surface of an overflow. Second, there is ground for believing that nearly all these ridges are the disconnected or repeated outcrops of only three trap sheets that have apparently been multiplied by faulting; so that the proof of overflow for one ridge would hold good for many others. Their separate origin by independent eruptions involves great complexity of arbitrary hypotheses; their origin in three periods of eruption allows the reduction of a seemingly most complicated structure to a relatively simple one and permits the correlation of many similar forms in a natural and connected system. It is not desired to affirm that all the central and eastern ridges can be referred to some one of these three periods, but there is good probability that three periods suffice to account for by far the greater number of ridges. Nor is it intended to imply that the trap sheets formed in these three periods were the products of single outpourings of lava, for evidence has already been discovered indicating that the posterior ridge at least is a composite flow of two or three dates, separated by intervals too short for the deposition of more than a thin film or coating of sediments. The evidence of the former continuity of the sheets now disjointed will be discussed in detail under a later head; it lies essentially in the similarity in the sequence of beds, both aqueous and igneous, encountered in crossing over one of the trap "mountains" from below the anterior ridge on the west to beyond the posterior ridge on the east, and when this similarity is recognized it is impossible to avoid the conviction that the several "mountains" and their subordinate anterior and posterior ridges are but repetitions of a single series of strata, broken into separate blocks, dislocated by faults, and curved by faint folding at a time when the general monoclinal structure was produced.

STRUCTURAL SIGNIFICANCE OF OVERFLOWS.

All the trap sheets of the central and eastern part of the formation except the undetermined ones by Farm River may, therefore, be treated as overflows, and as such they gain a great value as conformable members of the formation. Their resistance to erosion has enabled them to stand up in strong ridges, easily traced across the country, while the softer shales and sandstones are ordinarily worn

down and buried under the drift; it is, therefore, chiefly from the trap overflows that a knowledge of the structure of the Connecticut Triassic is to be obtained and a measure of its thickness determined. The structure is described further on, as far as it is now known.

SEQUENCE AND THICKNESS OF THE TRIASSIC SERIES.

The order and thickness of the Triassic deposits are determinable as soon as the faults whereby single beds may be repeated are detected and allowed for. Much more work in the field is needed before this can be done finally, and a good topographic map is necessary to make full use of the material thus gained; but a preliminary statement of the series as now understood may be permitted. The estimates here given are necessarily very rough and hardly represent more than the general order of the quantities involved. The column reads in natural order from top to bottom.

Beds	Thickness in feet.	
Conglomerates, sandstones, and shales	2,000 to	3,000
Posterior trap overflow	50 to	150
Sandstones and shales	300 to	500
Main trap overflow	300 to	500
Shales with thin limestone	100 to	300
Anterior trap overflow	50 to	150
Shales	500	500
Shales, sandstones, and conglomerates	3,000	3,000
Intrusive trap sheet	200 to	400
Sandstones and conglomerates	500 to	2,000
Total	7,000 to	10,500

It is very possible that an additional local layer of trap belongs somewhere above the posterior overflow and that another intrusion replaces the one here named in the southeastern part of the district.

Main trap overflow.—The most important member of this series, judging from its persistence as well as from its massive thickness, is the main trap overflow. It forms the great crescents of Pond and Toket Mountains, reappears in Paug Mountain and in the long ridge leading up to Middletown Mountain, is repeated in Lamentation Mountain and the short ridge supplementary to it on the south, rises again in the several masses of the Hanging Hills, and thence is easily followed in more or less disjointed ridges beyond the gap of the Farmington River. Its equivalent in Massachusetts has not yet been certainly determined, for, while the sheet that forms Mounts Tom and Holyoke is the heaviest of that region, the limestone that in Connecticut lies below the trap of the main ridge here lies above it. For this reason it may be that Mounts Tom and Holyoke are formed by the sheet called the anterior or amygdaloidal trap in Connecticut; this can doubtless be determined in another season's field work.

Anterior trap overflow.—The anterior, amygdaloidal or lower trap overflow may be mentioned next. It appears first at the northern hook of Toket Mountain; it is next found as a more or less continuous bench or ridge on the western slope of the "mountains" formed by the main overflow, even beyond the Farmington River, and it very likely extends into Massachusetts, as above suggested.

Limestone.—The little bed of limestone, described by Percival, is of peculiar interest and importance. At the time of the old State survey, about fifty years ago, this bed was quarried for burning at a number of points, but at present better lime is easily obtained from other districts, and nearly all the quarries are abandoned and obscured. Wherever found in Connecticut, this limestone bed always lies at the lower part of the shales, between the main and the anterior overflows; and this fact alone gives strong reason for concluding that its several different outcrops are repetitions of the same stratum. There is nothing inherently unlikely in this conclusion, while the reverse supposition, that the several outcrops represent separate beds, requires at least five independent but identical repetitions of a complex sequence of eruptions and depositions and is excluded by the very weight of its improbability.

Posterior trap overflow.—This upper overflow accompanies all the ridges of the main sheet from the seacoast up to and beyond the Farmington River. Its horizontal distance from the main sheet varies somewhat with the dip and thickness of the intervening beds, but not more than might be expected.

The remaining members of the series have not been mapped with sufficient detail for description at the present time, but, far as they are known, they present no contradictions to the hypothesis here outlined. From the work already done, there is good reason to think that an orderly arrangement of the whole formation may be determined by a fuller study, and, apart from its theoretical interest, this may be of value in guiding future explorations for the coal seams that have been suspected among the bituminous shales, in case any such work should be attempted again.

THE SOUTHBURY-WOODBURY TRIASSIC AREA.

The towns of Southbury and Woodbury, in western Connecticut, include a small Triassic area in the valley of the Pomperaug, about eight or ten miles north and south by three or four miles east and west. The trap ridges are numerous and make strong outcrops, but the sedimentary beds are seldom seen and no contacts between the two could be found in a week's careful search. The sequence of deposits, as determined in the southern part of the basin, is roughly given as follows: Several hundred feet of sandstones and conglomerates at the base; next a thin amygdaloidal trap; then two hundred or more feet of shales, containing fish scales and calcareous beds; then a

heavy sheet of trap. Other members were indicated above this, but they were everywhere covered with the plentiful drift. In the northern part of the basin the sandstones were hardly to be found; the trap sheets are there more expanded, consisting of heavy sheets below and above and an amygdaloidal sheet between; sedimentary layers are doubtless intercalated in this igneous series.

II. THE STRUCTURE OF THE FORMATION.

GENERAL ATTITUDE.

The appearance of a continuous monocline in the Connecticut Valley, with a general eastward dip of twenty or thirty degrees, is so distinct that the detail of structure whereby it is interrupted has received little attention. There are, however, good reasons for believing in interruptions of continuity by faults nearly parallel with the strike, with upthrow on the east in practically all observed cases, and also in departures from the eastward direction of dip in the neighborhood of the curved trap ridges and at some other points; and both these irregularities are of great significance in explaining the character of the mechanical deformation that the strata have suffered and the structural control of the peculiar topography of the Triassic areas.

CLASSES OF FAULTS.

The faults may be described, beginning with well proved examples of small throw and passing to more hypothetical cases of much greater displacement. It may be remarked, in introduction, that Prof. B. K. Emerson several years ago described a fault of moderate throw at Turner's Falls, in Massachusetts, which causes a single sheet of trap to do double duty and form two parallel ridges. About the same time the writer presented reasons for believing that Lamentation Mountain was but a repetition of the trap sheet that forms the Hanging Hills. The case may be now presented in greater fullness.

Oblique faults.—The first locality that threw light on the systematic arrangement of the faults was near South Britain, in the Pomperaug Valley, within the small western Triassic area, illustrated in Fig. 97. Here the paired outcrops of a conglomerate overlaid by the thin amygdaloidal trap appear five times in a third of a mile, every pair being distinctly out of line with its neighbors and the displacements always involving a moderate upthrow on the east of a fracture running obliquely to the strike of the beds. The actual fractures are, as usual, nowhere to be seen, as the outcrops have but little prominence on a grassy slope, but there can be no question whatever of their occurrence.

Returning to the Connecticut Valley, Pond Mountain, east of New Haven, a fine crescentic ridge formed by the southernmost outcrop

of the main trap sheet, presents several distinct examples of similar faults, always with upthrow on the east; they are to be found near its southern end, where the Shore Line Railroad and the highroad to Branford cross the ridge, and at several notches farther south; their displacement contributes liberally to the eastern curvature of the southern hook of the ridge. The relative attitude of the trap sheet to the underlying sandstone leaves no doubt of the existence of the faults; for, if the sandstone layers on the south of a fault were continued northward along their strike, they would lead directly into the trap on the north, and, besides this, every fault is indicated by a gap in the otherwise continuous trap ridge. The direction of the faults seems to be about northeast.

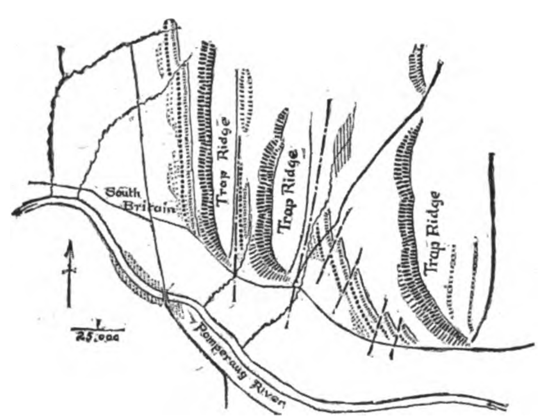


FIG. 97. Sketch map of the trap ridges near South Britain, in the Pomperaug Valley. The outcrop faces of trap ridges are marked with dark hachure lines; the amygdaloid is shown by short, faint hachures; conglomerate, sandstone, and shale are indicated by large dots, small dots, and lines. Four oblique faults dislocate the amygdaloid and conglomerate outcrops between the middle and eastern trap ridge. Larger faults separate the ridges themselves. A section of this district is given in Fig. 98.

A little ravine on the outside of the northern hook of Toket Mountain coincides with a dislocation visible in the lower surface of the trap, with an upthrow of about ten feet on the east; the topography of the ridge suggests the existence of several other breaks of this kind.

Faults of still greater throw, but otherwise similar to those of South Britain and Pond Mountain, are presumably the cause of the deep gaps that break through the Hanging Hills, northwest of Meriden. These are not yet directly proved by observed dislocation in the underlying sandstone, as its outcrops are few; but the attitude of the several hills as seen from the south is very suggestive of faulting, for the gaps are sudden interruptions in a massive lava flow that most reasonably must have been continuous when it was poured into the old Triassic sea and the bluffs stand a little higher on the east than on the west of the supposed fracture. In Percival's map of this district,

the lines drawn to indicate the boundary of the trap represent rather the boundary of the hills; the trap sheet is more nearly continuous than would be inferred from his outlines.

It is very probable that the deeply indented Holyoke Range in Massachusetts, the northern curve of the series of ridges that rise in the Hanging Hills at their southern end, owes its irregularity to similar transverse fissures. The trap sheet in every block of the ridge between adjacent gaps, as far as examined, has a strong dip to the southeast and strikes northeast and southwest, very obliquely to the general eastward course of the range; and the sandstone and conglomerates overlying the trap on the western side of the gap, if continued along their strike, would run into the trap sheet on the eastern side of the gap. The upthrow would in all cases be on the eastern side of the fault. The fault at Turner's Falls, described by Professor Emerson, is of similar character.

A number of faults, closely related to those just described, must be inferred between the trap ridges north of the Hanging Hills. The gaps on the range here run obliquely about thirty degrees east of its general northward trend, and the supposition that these gaps mark fissures with upthrow on the east would account for the systematic overlapping attitude, or, as Percival called it, the "advancing order" of the successive members of the range, Short Mountain, High Rock, Farmington and Talcott Mountains and others. The gaps do not break through the main trap sheet alone, but interrupt the anterior amygdaloidal ridge and its overlying limestone in a most systematic manner. The probable cause of the oblique intersection of the range by the faults and the reason for the advancing order of overlaps in its several members will be presented later.

Strike faults.—All the examples thus far described are of tolerably easy recognition, because the dislocation is not great and corresponding members of the formation may be seen not far out of line on the two sides of the fracture. In all such cases the fault line makes a considerable angle with the strike of the faulted beds, but in the examples yet to be considered the fault line is essentially parallel to the strike, and therefore causes repetition of strata in a series of parallel outcrops; and at first sight the corresponding members in such cases are entirely independent and unrelated. The first clear evidence of this structure found by the writer was again close to South Britain in the Pomperaug Valley, which may therefore be said to have furnished the key to the Triassic structure. Although far separated from the Connecticut Valley, the topography and the implied structure of the two areas are so closely alike that it seems legitimate to carry evidence from one to the other. In this interesting locality a single series of beds, consisting of the conglomerate, amygdaloid, shales, and heavy trap already mentioned, is faulted so as to present three successive outcrops, with upthrow always on the east,

as shown in Fig. 98. The beds in each block vary somewhat in dip, but in other respects are closely similar. If the trap sheets had been sedimentary rocks, the repetition by faulting must have long since been discovered. A short and low ledge of trap in the northern part of the valley that follows the westernmost fault line is the only obscure member of the series, and this may be regarded as a small mass of trap standing between branches of the fault.

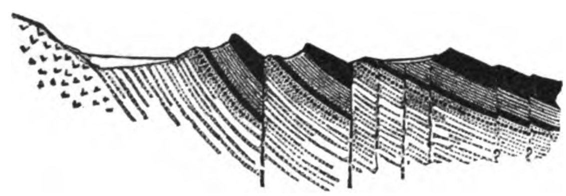


FIG. 98. Inferred structure of the district shown in Fig. 97. The two faults of larger throw, by which a single sheet of trap is repeated in three ridges, are proved by the threefold repetition of a series of beds comprising sandstone, conglomerate, amygdaloidal trap, shale, and heavy trap.

It will be remembered that no evidence could be given in the first section of this report as to the intrusive or overflow origin of the trap sheets in the Pomperaug district; but an argument based on the faults just described gives sufficient reason for supposing that, whatever their origin, the sheets had their present position in the stratified series before the tilting and faulting took place. There are only three suppositions to be considered; first, that they were overflows; second, that they were intrusions, thrust in before the faulting; and, third, that they were intrusions thrust in during or after the faulting. In either the first or the second case, they necessarily were tilted and faulted with the adjacent stratified beds. The third case may be excluded by the reductio ad absurdum, for it requires that six separate intrusions should arrange themselves independently in a determinate and systematic manner. The same line of argument may be applied to several other trap ridges of this district.

The ridges east of Woodbury (Fig. 99), in the same western Triassic area, offer another illustration of the same faulted structure, although the evidence for it might commonly be thought less conclusive, because it does not rest on a repetition of sedimentary strata; but a visit to the spot leaves little doubt as to the meaning of the structure. The ridge-making beds in two similar groups of hills east of the village consist of a lower and an upper sheet of compact trap, separated by an amygdaloidal layer; shales probably occur between these sheets, but they are nowhere to be seen. The similarity in the structure and topography of the two groups is so striking that one cannot resist the belief that they are composed of the same set of trap sheets, repeated by a fault with upthrow of five or six hundred feet on the east in the intermediate valley. The several low ledges of

unevenly jointed trap on the western side of the valley may be fragments of the sheets caught in the fracture, as suggested in the figure.

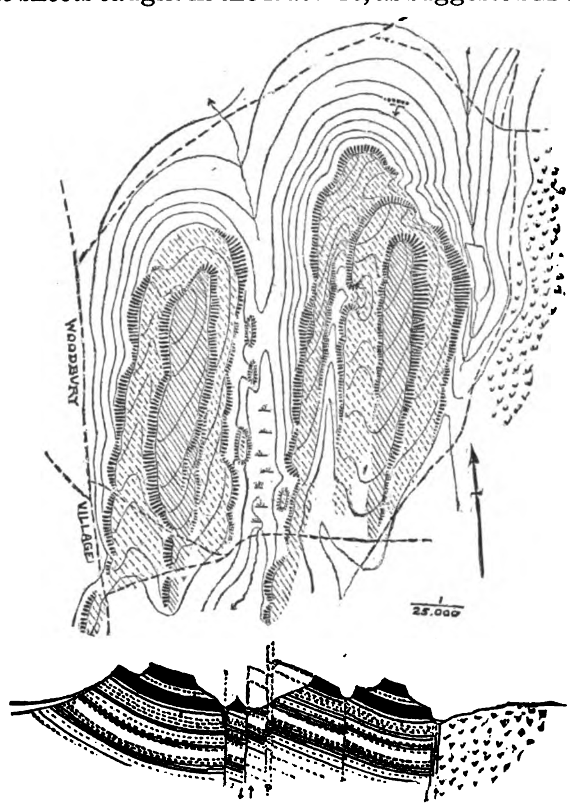


FIG. 99. Map and section of trap ridges near Woodbury. The topography is indicated by sketched contours, with hachures for trap bluffs. The lower sandstone slopes are all covered and the northern bluff of the western group of ridges is quite buried in drift. The crystalline rocks appear on the east. The section suggests an interpretation of the surface forms.

Faults of the same character and of equal or greater throw must occur in several parts of the Connecticut Valley, if the line of argument thus far followed be carried to its legitimate conclusion. The doubt in certain cases lies entirely in the difficulty, caused by the heavy drift covering, of finding a sufficient number of outcrops to establish the complete sequence of beds already described, and not in any contradictions where the beds are seen or in any inherent improbability of a faulted structure; and it must be borne in mind that the systematic relation of these strike-faults to one another and to the faults already described counts strongly in favor of their occurrence. They may be described in order from south to north along the main trap overflow, after noting that the separation of the crescents of Pond and Toket Mountains is caused, not by a fracture, but by a transverse anticline, as will be described below.

A fault of nearly one thousand feet throw may be inferred between Toket and Paug Mountains; a fault of less throw probably runs

through Paug Pond, separating Paug Mountain from the long range that runs north between Durham and Wallingford, and rises between Middletown and Meriden, in the high ridge known as Middletown Mountain, near its northern end; similar displacements explain the separation of Lamentation Mountain from Middletown Mountain and the breaking of the former into two parts. Lamentation Mountain and the Hanging Hills must still be considered parts of the same main sheet, dislocated by a fault of several thousand feet, the largest of the series, in the valley followed by the New Haven and Hartford railroad. In all these mountains the same sequence of beds is more or less completely presented: a sandstone with shales at the base of the western slope, a bench or ridge formed by the amygdaloidal trap of the anterior sheet, a series of shales with a limestone bed near its base next in order, the heavy trap sheet forming the main ridge, this overlaid with sandy shales, and followed at last by the posterior ridge or upper trap sheet. Going farther north, the oblique faults already mentioned are encountered.

Marginal faults.—A very considerable fault or series of faults is indicated along the eastern margin of the formation, for this only can explain the sudden appearance there of the crystalline rocks, in face of the continuous eastward dip of the bedded series close to their boundary. This is especially conspicuous in the district of the two southern crescentic ridges from Durham to the Sound; the beds here are often coarse conglomerates, undoubtedly derived from the crystalline ledges to the east, and yet their dip is persistently to the east up to the very last outcrop visible, excepting in the hooks of the crescents, where the attitude of the beds changes, as will be shown below. The measure of the total upthrow of the crystalline rocks along the margin of the formation will depend on the number and value of the step-like faults west of it; but on the east of Pond and Toket Mountains the throw must be several thousand feet.

SYSTEMATIC ARRANGEMENT OF FAULTS.

The faults now described are arranged in a systematic manner. The upthrow is always on the east, so that a single bed is repeated in several outcrops and the directions of the faults in certain definite areas are essentially parallel, for the difference between the strike-faults and the oblique faults does not arise so much from a change in the direction of the fractures as from a change in the strike of the fractured beds. All the numerous faults south of Hartford trend north-northeast or northeast. Farther up the valley, they turn more to the west, and for a time run north or north-northwest. It is owing to this systematic arrangement of the faults that the adjacent trap ridges overlap in the orderly manner that impressed Percival as one of their most peculiar features. On the southern half of a crescentic curve that is made up of several dislocated and overlapping mem-

bers, such as Pond Mountain, in a small way, or the Hanging Hills, on a larger scale, the south end of a northern member always stands west of the north end of a southern member, thus forming the "advancing order" of Percival, as in Fig. 100; on the northern hook of

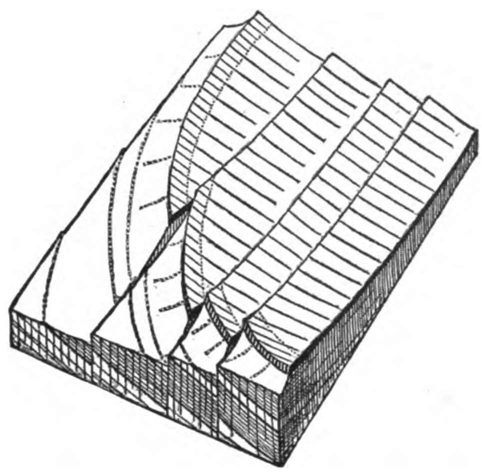


Fig. 100. Arrangement of overlap produced when the beds strike to the left of the fault line; advancing order.

the crescents, this is reversed into the "receding order," as in Fig. 101, that characterizes the range from Bloomfield, Conn., to the Holyoke Range in Massachusetts and is found again in corresponding attitude

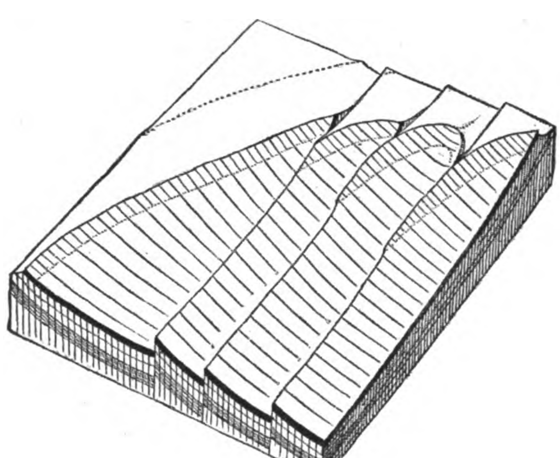


Fig. 101. Arrangement of overlap produced when the beds strike to the right of the fault line; retreating order.

on the north end of the Deerfield trap sheet at Turner's Falls. It should be remarked that it is not the crescent that compels this orderly arrangement, but the arrangement that compels the crescent. Besides this, there is necessarily a tolerably constant proportion be-

tween the throw of a fault and the overlap of the adjacent ridges, and in this is to be found the reason for a well marked peculiarity of the Triassic topography; in following the main trap ridges northward, the westward offset of the successive mountains is proportionate to their southward overlap. The systematic arrangement of the faults, therefore, deserves as much emphasis as the occurrence of the faults themselves, and a less complete chain of evidence suffices for their demonstration than would properly be demanded in case they were without visible relationship.

The obscurity of the Triassic monoclinal structure has been greatly increased by a general belief in the Post-Triassic intrusion and disturbing action of the trap sheets; for, if the sheets had been sedimentary beds, like the mountain-making sandstones in Pennsylvania, hardly any other explanation than the one here suggested could be imagined to account for their repeated appearance. Being of eruptive origin, ordinary stratigraphic interpretation has been long denied them. Once fully recognized as contemporaneous overflows, they take their proper place as guides to the structure of the whole formation.

The faults thus far considered have all been discovered where they intersect the trap ridges; but it must not be inferred from this that they are limited to these localities and that no faults occur in any other. The fractures are probably continued along their strike for a distance many times greater than their throw, and the larger master-faults may run ten or twenty miles or more. Many faults may be limited to the sandstone areas, and thus for the present elude detection. It is probably in some such way as this that explanation will be found for the evident general relation between the curvature and interruptions of the overflow and intrusive trap sheets. Their curves are convex in the same direction, their members overlap in the same order, and the similarity in the disposition of the two series of ridges is too great to be attributed to independent forces. No faults are yet directly proved by the repetition of a sequence of strata about the ridges of the intrusive sheet, and their independent discovery is made difficult by the absence there of subordinate sheets parallel to the main intrusion and of a guiding limestone bed; but an examination of the ridges on the ground and an inspection of Percival's map strengthen the conviction that the intrusive ridges are subject to the same system of dislocation as that discovered among the overflow ridges. It is, of course, possible that intrusions should occur after the general disturbance of the formation as a whole and that the intrusive lavas should be guided into curved sheets, following the attitude of the bedded rocks; but it can hardly be thought possible that the disconnected members of such intrusions should arrange themselves so as to overlap in the same order as that found in the overflow sheets several miles away. The intrusive sheets, there-

fore, as already stated in the first division of this paper, must be regarded as having taken their place in the formation, like the overflows, before the period of tilting and faulting, while the strata were still continuous and horizontal. Their value as guides to structure is much less than that of the overflows until they are demonstrated to follow the bedded rocks conformably, and this demonstration is difficult in a region so heavily drift-covered.

FAULTS WITH REVERSED THROW.

The rule that faults have the upthrow on the eastern side is open to few exceptions. Perhaps half a dozen cases are known in quarries and cuttings where uplifts of a few feet on the western side of a fracture have been noticed; but these have no effect on the topography and would hardly claim mention were it not for the suspicion that the western margin of the formation, in some localities, is cut off by a fault of considerable strength, with this reversed direction of throw. This suspicion is based on the variable distance between the western ridges of intrusive trap and the boundary of the formation as marked on Percival's map, and therefore assumes, in the first place, that the intrusive sheet has an essentially conformable attitude in the sedimentary series; in the second place, that the sediments do not rapidly vary in thickness; and, in the third, that the boundary is correctly mapped. The first assumption is not contradicted wherever the attitude of the sheet can be determined, little is known about the second, and the third is warranted by the confidence gained in the remarkable accuracy of other parts of the map. There is, to be sure, much heavy drift in many parts of the marginal region, for the boundary in nearly all its length follows a valley, and it remains for future investigation to determine whether the suspected fault really exists; but meantime the possibility of such a fault should be accounted for.

FOLDS OF THE CRESCENTIC RIDGES.

A second style of departure from the generally accepted monoclinal structure is the change in the strike and dip of the beds so as to maintain a conformity with the curvature of the crescentic or hooked trap ridges, to which reference has already been made. The curvature of the ridges with their convex side to the west has long been noticed. Percival recognized it as a general form, and detected the parallelism between the aqueous and the igneous beds in this type of structure; he made especial mention of the latter peculiarity in the striking example near Beckley Station, described below. Hitchcock found it in Massachusetts, but did not follow it in detail and was probably unaware of the completeness of its display in southern Connecticut.

The hook at the northern end of the curved trap ridge near Beckley Station, on the Berlin and Middletown Railroad, is small enough for easy observation; its curvature is sharp and the sandstone outcrops near it are numerous enough to make a satisfactory case. The trap sheet changes its strike by 120° in half a mile, and its dip of 25° or 30° is always directed toward the center of its curve; the sandstone below it presents just the same changes of attitude. Curvature of outcrop like this on a generally horizontal surface clearly implies a faint folding or dishing of the beds that appears to be thoroughly characteristic of Triassic structure.[1] It is repeated over and over again on a larger or smaller scale and, when associated with faulting, gives sufficient reason for the many curious topographic forms of the Connecticut Valley. The absence of outcrops on the eastern side of the "dish," where the curvature would consequently be convex to the east, is to be accounted for by the eastward dip of the "dish" as a whole and by the occurrence of faults along its eastern side. This is neatly shown at Beckley, where the fault that truncates the "dish" is indicated by a repetition of the same detail of topography in a second curved trap ridge immediately east of the hook that terminates the long curve of the first.

Pond and Toket Mountains (Fig. 102) give an ideal illustration of this structure. The first is the simpler form of the two. In spite of the strong bending of the trap sheet that forms the ridge, the adjacent beds above and below it depart in the same way from the general strike of the monocline. This is, to be sure, only a corollary to the demonstration of the contemporaneous overflow of the trap sheet upon the bedded rocks, but it is an interesting and valuable one. The parallelism appears not only along the main ridge, but in the neighborhood of the posterior trap sheets as well. The latter are peculiarly suggestive, as the two ridges, called by Percival the first and second posterior ridges, are almost certainly the western and eastern outcrops of a single trap sheet; for here alone in the whole Triassic area is the truncating fault far enough away to allow both sides of the trap "dish" to reach the surface; here only is a trap ridge found convex toward the east. It is most satisfactory to find that so thoroughly exceptional an occurrence admits of so simple an explanation, completely in sympathy with that given to the whole region. The first or normal posterior ridge dips to the east and is convex to the west; the second has its faint convexity eastward and the sandstones below and above it dip to the west. Unfortunately, the complete oval outcrop of the sheet is interrupted on the northeast and southeast, where the trap is either hidden under drift or carried away by irregular faulting. It is, indeed, by but a small distance that the eastern outcrop escapes concealment in the present

[1] This explanation of the crescentic ridges was suggested by the writer several years ago. See Bull. Museum Comp. Zoöl. Harvard Coll., vol 7, No. 9, 1883.

stage of denudation, for the crystalline rocks appear only a few hundred feet east of it, and the trap itself is much disturbed and broken, as if the heavy fault that here follows the margin of the formation had run close by it and shattered it.

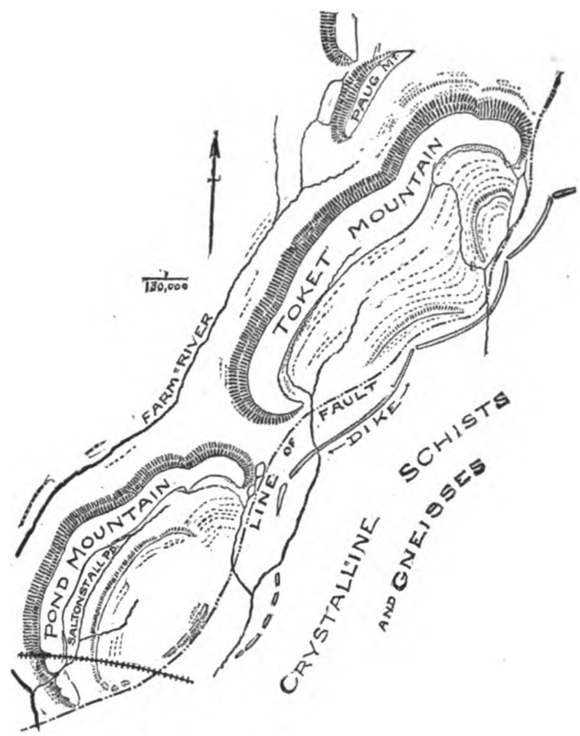


FIG. 102. Map based on Percival's map, from which it is enlarged with the addition of certain details. The outcrop bluffs of the trap ridges are shaded with hachures. The name of each mountain is drawn on the smooth slope formed by the upper surface of the trap sheet. Dotted lines indicate the curving strike of sandstones and conglomerates. An irregular fault line separates the Triassic from the crystalline rocks (see Fig. 103).

The hooks at the ends of the Toket Mountain crescent next north of Pond Mountain are strongly turned in; the adjacent beds follow them accurately wherever visible. A significant variation on the simple type of Pond Mountain is found here in the indentation of the western face of the ridge a little north of its middle, as if it were affected by the faint beginning of a transverse anticline which, if carried to its completion, would separate the mountain into two parts. Such a separation is already accomplished in the posterior ridge (Fig. 103), whose two curved members correspond to the northern and southern lobes of the main crescent; their eastern outcrops are cut off by the strong marginal fault. The sandstones and conglomerates within the crescent also present a double curvature, perfectly in sympathy with the turning of the trap sheets. Toket Mountain may indeed be regarded as showing in an uncompleted

form the very structure which, when further evolved, has caused the separation of the Pond and Toket crescents in the present stage of erosion. As the degradation of the surface progresses, the indentation of the western margin will become deeper and deeper, until at last, if sufficient depth of erosion be allowed, the main ridge will be worn into two separate members. The once continuous posterior ridge has already reached this stage. It cannot be doubted that the main trap overflow once stretched over the valley that now divides the Pond and Toket crescents, whence it has been worn away in the reduction of the surface to the present form.

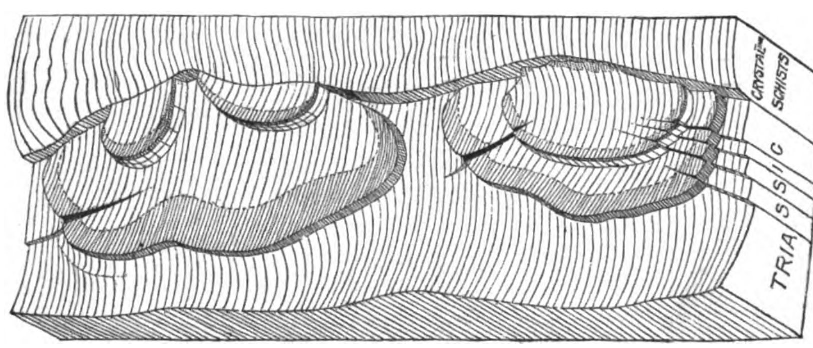


FIG. 103. Bird's-eye view of an ideal dissection of Pond and Toket Mountains mapped in Fig. 102. The fault separating the Triassic and crystalline rocks is drawn as a vertical face ; the exposed slopes of the trap sheets are shaded with closer lines than those drawn over the rest of the surface. Although lacking detail, the diagram may serve to illustrate the homology between the two parts of the main trap sheet in the separate mountain ridges and the two parts of the posterior sheet in the small ridges within the Toket crescent.

There are no other examples so simple as these. The great range that curves from the Hanging Hills on the south to the Mount Holyoke range on the north and the smaller Deerfield range are complicated by faulting, as already described; but in as far as they are curved they correspond closely with the typical structure of the crescents. Their attitude is very significant in one respect. On the assumption that their trap sheets were once of larger area than at present—and this is not at all improbable, for it is likely enough that they are dissevered parts of a single sheet—some reason should be found why they turn so strongly toward the eastern margin of the formation about Amherst and leave so large an area free from trap between them. The simplest reason for this is that the Amherst district between the two trap curves has been elevated more than the country north or south of it. This in turn would require that the foundation of the Triassic formation should here approach nearer to the present surface of the ground than it does elsewhere. Now, it is precisely in this part of the whole Triassic area that the only outcrop of the fundamental crystalline rocks appears, forming Mount

Warner. This separation of the Mount Holyoke and Deerfield ranges would therefore appear to be a large example of a late stage in the process so faintly begun in the indentation of the western face of the Toket crescent. The absence of a ridge of intrusive trap near the eastern margin of the Mount Warner crystalline area confirms what has been said as to the limitation of intrusive sheets to Connecticut.

It may be mentioned that the little ridges north of Toket Mountain, marked with much detail of curvature on Percival's map, are disappointing when examined on the ground. Their outcrops are very irregular, not nearly so smooth and continuous as the map indicates, and no adjacent sandstones are visible. No definite statement can be made concerning their arrangement.

The influence of curvature of the trap sheets on the topography of the valley is especially instructive in illustration of the variety of form developed by slight changes in a simple type of structure, and, with the exception of the smallest ridges, no form is presented in duplicate. It is as if one example of each stage in the variation is all that should be needed to enforce this lesson.

SUMMARY OF STRUCTURE TO BE ACCOUNTED FOR.

The simplicity of igneous action implied by regarding all the many trap ridges as the product of a few intrusions and eruptions and the ease of explanation gained by looking upon curved ridges as the outcrops of slightly folded beds are equaled by the economy of material allowed by associating a series of step-faults with the monoclinal attitude of the formation. A thickness of thirty or forty thousand feet would be required if the monocline were unbroken; about ten thousand may suffice if faults occur as commonly in the sandstone areas as among the trap ridges. We must therefore conclude that, whatever hypothesis is suggested for the mechanical origin of the Triassic structure, it must explain how the whole series of beds, igneous as well as aqueous, has been broken into a number of long, rather narrow, parallel-sided blocks, how the beds in every block have been tilted over to the east and sometimes faintly bent into dish-like form, and how the blocks are all dislocated by faults with upthrow almost constantly on the eastern side.

MECHANICAL ORIGIN OF THE TRIASSIC MONOCLINE.

CONDITIONS OF THE PROBLEM.

It will be well, in entering on this problem and before attempting its solution, to consider its conditions and requirements. These may be best appreciated by following the historical method and reviewing the suggestions that have been made towards its explanation.

Oblique deposition.—The idea once advocated that the present attitude is the original attitude, and that the monoclinal structure is

simply an extended example of oblique deposition, is inadmissible: First, because in such case the conglomerates on the eastern side of the formation in the Connecticut Valley could not dip, as they do, toward the land from which their fragments were derived, and, second, because the evidence of faulting, accompanied by tilting, is too distinct to be longer overlooked. The first condition of the problem is therefore the simple one that the strata have actually been disturbed in some way, and do not now lie as they were deposited. This is almost self-evident, and is mentioned chiefly from its historical interest and to clear the ground for what follows.

Contemporaneous disturbance.—It has been suggested in explanation of the Triassic monocline in New Jersey, which in many respects is similar to that of the Connecticut Valley, that the tilting went on progressively with the deposition. Apart from the mechanical difficulties that this involves, it would be inapplicable to the Connecticut Valley, because it presents no explanation of the systematic repetition of the similar sequences in the deposits already mentioned. It has been shown above that the similarity of the sequences is best explained by supposing the corresponding members in different localities to be parts of a once continuous single stratum, either aqueous or igneous, while the repetition is regarded as the effect of faulting subsequent to the time of deposit of the uppermost repeated stratum. We thus have the second condition that, at least as far as the Connecticut Valley area is concerned, the disturbance occurred after the deposition was essentially completed, and therefore involved the whole thickness of the formation.

Disturbance by intrusions.—The constant association of numerous trap ridges with the Triassic strata early gave rise to the supposition that the outburst of their igneous rocks was the sufficient cause for the tilting of the adjacent aqueous beds. This was perhaps natural enough at a time when the disturbance accompanying intrusion and eruption was exaggerated, and when the contemporaneous origin of many of the trap sheets had not been perceived, but from the present point of view it is inadequate. In the first place, the greater number of the Connecticut trap sheets are old overflows, contemporaneous in origin with the strata that inclose them and with which they have therefore been passively disturbed by external force. Further, the dikes that have been discovered breaking across the bedded rocks exert no noticeable influence on the attitude of the beds about them, and the few trap sheets that have been intruded among the lower strata are almost limited to the western border of the formation in Connecticut. They do not appear in Massachusetts. No peculiar attitude or structure is to be found in the strata adjacent to them that cannot be, both in quality and quantity, paralleled or exceeded in other parts of the formation. Their ridges are curved and interrupted in essentially the same manner as that so characteristic of the larger

ridges of overflow sheets. In this connection it may again be noted that dikes and intrusive sheets are well known elsewhere in regions of horizontal strata where their entrance has produced no more disturbance than was necessary to give them room; and it should be remembered that to admit the theory that the Triassic disturbance was caused by the trap intrusions is accepting an explanation that does not explain, for no sufficient reason has yet been given to show why the intrusions should take shapes at once so peculiar and so systematic. Therefore, when it is seen that the peculiar attitude of the intrusive sheets, in all essential features, is imitated in the attitude of the overflow sheets that cannot possibly have been concerned in their own distortion, it is legitimate to conclude that the distortion was accomplished by a force external to both intrusive and overflow sheets, which together yielded before it.

The third condition of the problem, therefore, requires that the disturbing force shall act upon the formation from without, after the entrance of the intrusive trap sheets, and that the whole formation shall passively suffer under this disturbance.

General tilting and faulting.—The explanation of the monoclinal structure that has been most commonly followed regards it as the result of a broad tilting, with more or less vague faulting, of a once horizontal formation by an undefined external force. This explanation also leaves much to be explained, but it is satisfactory in so far as it involves, at least by implication, a disturbance not only in the Triassic strata, but in the fundamental and adjoining crystalline rocks as well; for it is reasonable that the area over which the disturbance acted should not be closely limited to the area where its effects are now seen in the tilted sandstones and traps; nor should its penetration below the surface be measured merely by the depth of the Triassic formation. A great depth of penetration is indeed required by the magnitude of the faults, already described. It cannot be supposed that the disturbance which originated the faults that dislocate the main trap overflow faded away within the thickness of the Mesozoic rocks; it is demanded by the surface structure that the faults have depth proportionate to their throw and commensurate with their length, and this would carry them far down into the underlying schists and gneisses. This is, moreover, entirely in accordance with the hypotheses concerning the general deformation of the earth's crust; the thickness of rocks involved in the deformation may indeed be measured by tens or hundreds of miles. A fourth condition thus demands that the external disturbing force required in the third shall affect a greater mass than that of the Triassic rocks alone.

Relation of several Triassic areas.—It has been suggested in recent years that the eastward monocline of the Connecticut Valley and the westward monocline of New Jersey might be lateral remnants

of a broad Triassic area whose central part had been high uplifted, forming a broad, anticlinal structure, the arch having been worn away, leaving only the buttresses remaining. It may be remarked that the former continuity of the Triassic strata across the whole breadth of the supposed arch is not essential to this explanation and that the occurrence of locally supplied conglomerates on the western side of the Connecticut Valley area, and probably also on the eastern side of the New Jersey area, points against it. The suggestion has, however, the strong recommendation of recognizing that there was some community of disturbance in the adjacent Triassic areas and that the disturbance affected broad areas and great depths of the earth's crust in a systematic manner. The similarity of the several Triassic areas on the Atlantic slope is very striking. From Nova Scotia to the Carolinas the several isolated strips of this formation present many resemblances, not only in materials, but also in attitude and structure. This is especially the case in regard to the areas in Nova Scotia, the Connecticut Valley, the little Southbury-Woodbury district in western Connecticut, and the large extension in New Jersey and Pennsylvania. Just as the similarity in the old lavas over all these areas points to their origin from a deep-seated source, as Professor Dana has suggested, so the similarity in the character of the distortion that they have suffered points to a general rather than to a local force for its production.

This fifth condition, therefore, indicates that the disturbing force was felt over a region so large as to embrace several of the isolated Triassic areas, and, further, it at least suggests that the action of the force and the character of the resulting disturbance were determined less by the structure of the relatively local and superficial Triassic deposits than by that of the wide-spreading and deep-reaching crystalline mass on which they generally rest.

Character of the disturbing force.—The character of the disturbing force that produced the monoclinal structure cannot be sharply defined, but the following considerations may give some indication of it. The several Triassic areas are associated rather closely with the eastern margin of the greater area of Appalachian disturbance. Their trend is approximately parallel to the larger structural lines of the mountain system, and the depression of the troughs in which their beds were collected as well as their subsequent deformation may be naturally associated with a continuation of the disturbances that had in Pre-Triassic time accomplished the greater part of the Appalachian folding. The structure of the whole region is consonant with this supposition, for it bears many marks of yielding in sympathy with the Appalachian system. It will therefore be well to bear in mind a probable sixth condition, that the disturbing force, whose magnitude and area of application were defined in the fourth and fifth, was a long-enduring and slow-acting horizontal compression, exerted in an east and west or southeast and northwest direction.

Having reached this point of view it may be found profitable to leave the Triassic strata out of consideration for a time and give more attention to the rocks that underlie them.

ACTION OF COMPRESSION ON TILTED SCHISTS.

The fundamental rocks have already been described as schists and gneisses, generally dipping at steep angles; their strike is variable, but in the region of the Connecticut Valley it is commonly somewhat east of north. How would these fundamental rocks yield if acted on to great depths by a horizontal compression force, directed at right angles to their general strike? A brief digression may be permitted for the more deliberate approach towards the answer to this question.

A homogeneous part of the earth's crust, subjected to a horizontal crushing force, yields by minute, intimate rearrangement of its parts, whereby its horizontal measure in the line of the force is diminished and its compactness and vertical measure are proportionately increased. The development of cleavage and foliation is generally associated with this kind of deformation.

A region composed of stratified or laminated rocks yields, under the same conditions, by slipping one surface on another, accompanied by more or less bending. If the laminæ or slabs are not already at right angles to the compression, the surface of the region is elevated and its breadth is reduced. If the strata are horizontal, as in cases ordinarily considered, they will escape from a horizontal crush by folding or wrinkling, the measure of the corrugations depending in part on the thickness of the strata. Such folding ends when the divisional planes are at right angles to the compression, the folds are then "closed," and further compression is accomplished by intimate rearrangement.

If the laminæ plunge at about a constant angle through the whole depth of the mass possessed by the compression, they will slip upon one another as they are tilted over, so as to bring the divisional surfaces more nearly at right angles to the compression and no folds need appear. If the dip of the laminæ vary with the depth, they will generally yield by changing their attitude so as to smooth out their corrugations and become straight and vertical. In both cases the surface of the region will be elevated.

If the force of compression vary with the depth, so as to introduce a shear, deformation by slipping of slab on slab may continue after the slabs are at right angles to the direction of the force. Overturned beds are presumably connected with some such style of distortion.

There is necessarily, in natural cases, a general interaction of these various processes. Heavy compression will produce intimate rearrangement at the same time with folding or tilting and slipping.

The relation of the processes will depend largely on the texture and attitude of the rock masses. In a case where the yielding chiefly takes the form of tilting and slipping, it must be noted that the number of slipping surfaces, or "faults," and the amount of motion upon them, or "throw," will vary along the strike of the schists with the variation of schistose structure. When the slabs are thin and offer equal ease of slipping, many faults close together and of small throw may be formed. Where massive gneiss occurs, the slabs may be much thicker between the divisional planes, and the faults will be fewer and probably of greater throw.

FORMATION OF THE FAULTED TRIASSIC MONOCLINE.

The attempt may now be made to apply these processes to the case of the Connecticut schists and gneisses, remembering that they have probably been disturbed to great depths and that they are covered with a relatively shallow layer of Triassic strata. Their condition is roughly illustrated in Fig. 104. As they are here supposed to be in the attitude they held before the Triassic monocline was formed, their position is necessarily somewhat a matter of conjecture; their regularity is probably exaggerated. Two dikes are added to the diagram, one on the left to feed the intrusive trap sheet, the other on the right to supply the successive overflows that appeared at certain times during the depression of the basin and the accumulation of the sediments; three volcanic cones are indicated at the points where the second dike came to the surface during its periods of activity. All

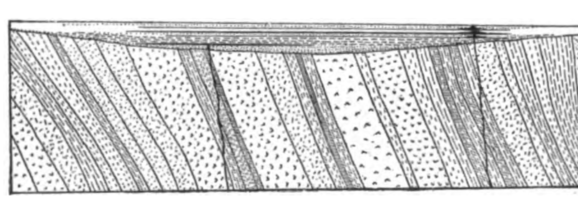


FIG. 104. Transverse section of the Triassic strata lying horizontally and undisturbed on the steeply inclined slabs of schist. It is required to find some means of deforming the whole mass so that the now horizontal strata shall take the attitude of a faulted monocline (see Fig. 105.)

of this, of course, is highly diagrammatic; the vents or fissures from which the overflows were supplied are not yet identified and may have been at different points; the dike that fed the intrusion is still undiscovered. Nothing definite can be said as to the number of divisional planes that will be formed between the great slabs of schist and gneiss or of the amount of slipping upon them when the crush comes; but they may be represented by the structural lines in the figure. The upper edges of the slabs have been worn down by Pre-Triassic erosion, so that every slab is beveled off at such an angle with its dip as to form a continuous and nearly level land surface on which the Triassic deposition began when the region as a whole was depressed and submerged.

Deposition continued while depression lasted, but it was stopped when the fundamental schists began to writhe and rise under the growth of the irresistible compression. The great slabs slip one on another; their dip is increased, and on the east they are even thrown over past the vertical. Their upper surface, on which the Triassic beds rest, is no longer united, continuous, and nearly level; the slabs are separated by faults of greater or less throw and their beveled edges are canted over at an angle equal to their change of dip. The overlying beds, unable to support themselves unbroken on this uneven foundation, settle down upon it as best they may. It seems as if an explanation of the Triassic monocline might be found in some such mechanism as this.

The result is illustrated in Fig. 105. The essential characteristics of the Triassic structure appear at once. The dip is all in one direction and of tolerably constant amount as long as the slabs of schist are canted over to the same side, whether the dip of the slabs is constant or not. Numerous faults fracture and dislocate the unconformable surface layers; the length of the faults and the amount of throw vary, depending on the continuity and thickness of the slabs of schist beneath; the upthrow is on the side of the direction of dip, without regard to the hade of the fault; the strike of the schists determines the direction of the faults.

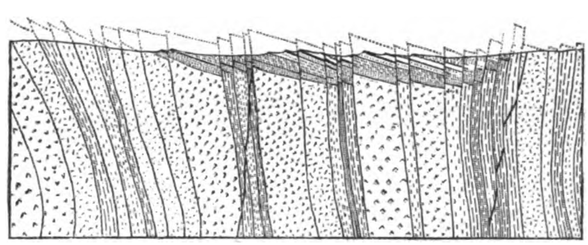


Fig. 105. Faulted monoclinal attitude produced in the Triassic strata by pushing the underlying slabs of schist over to the right. It is not desired to affirm that the fault planes in the Triassic strata will be in direct continuation of the divisional planes in the schists below; but only that the position of the faults will be determined by the dislocation of the schists. The hade of the Triassic faults is not known.

This last point offers satisfactory means of testing the hypothesis. The systematic arrangement of the faults and their oblique intersection with the trap ridges have already been described; these are most conspicuously exhibited about the Hanging Hills and farther south. After carrying the hypothesis thus far, it was a gratification to find that, on prolonging these oblique fault-lines until they reached the crystalline rocks to the northeast and southwest, they led directly to districts where, according to Percival's map, the strike of the gneisses and schists is most regularly developed and in a direction that coincides closely with the line of the faults. The accordance is most distinct, and it can hardly be doubted that the strike of the controlling fracture-lines in the Hanging Hills is determined by the trend

of the structure-lines of the old rocks beneath them. It remains to be seen whether the change from the "advancing" order of overlap in the southern district to the "receding" order shown farther north in the Barn-door Hills of Granby will admit of similar explanation.

The solution of the problem need not be followed further until additional tests are applied to it in the field. One of these tests will be the examination of the adjacent schists to determine whether they are faulted or not, as the hypothesis indicates. There are, however, two special cases that need consideration, namely, the shallow, boat-like folds that determine the crescentic outcrop of the trap ridges, and the suspected fault along part of the western margin of the formation, with upthrow on the west, instead of on the east, as usual.

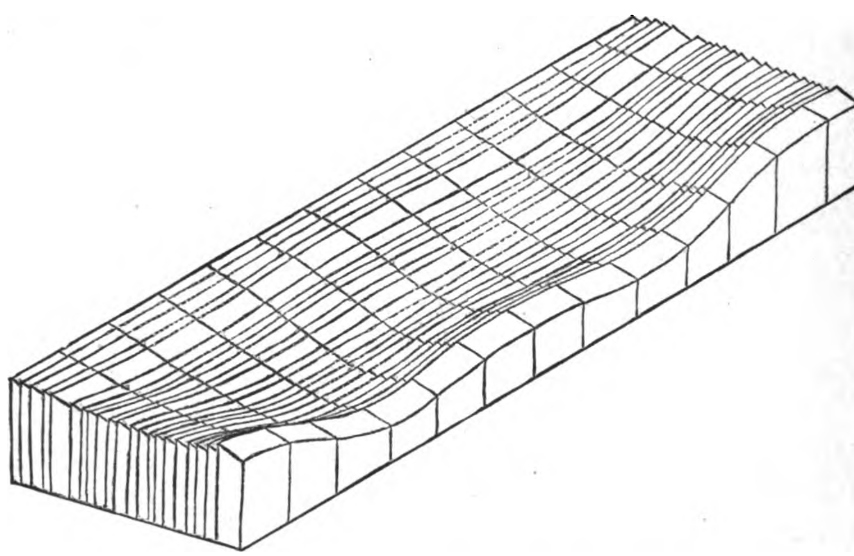


FIG. 106. Production of an uneven foundation, such as the strata of Toket Mountain may be supposed to rest upon, by means of unequal slipping or faulting at different parts of the many surfaces that separate the slabs of schist of which the foundation is composed.

Origin of the crescentic ridges.—The size of the crescentic curves varies so greatly as to suggest different processes in their formation. The faint folds on which they depend may be in part the direct result of lateral compression, as perhaps in the small curve described near Beckley Station. But their association with faults is too important to be overlooked; it may be seen on close examination in Pond Mountain; it is conspicuous in the curving ends of the great Hanging Hills, Mount Holyoke range. It is therefore advisable to ascribe the flat folds as well as the faults to some reaction from the rocks beneath, and a sufficient cause for this may be found in a change in the number and the amount of dislocations in the slabs of underlying schist in passing along their strike, as illustrated in Fig. 106. The beds lying on a foundation thus molded might accommodate themselves to it by simple folding, if the slabs of schists were thin and

their faults small, and thus such a structure as that of Toket Mountain might be produced; if the slabs were thicker and the faults heavier, the dislocations would appear at the surface, as in the Hanging Hills. A cause for such changes in the value of the displacements as are here indicated is suggested in the next paragraph.

Faults with reversed throw.—The occasional occurrence of minute faults with upthrow on the western side of the fracture might be ascribed to unexplained accident, without injury to the main hypothesis; but the suspicion of a strong fault along part of the western margin of the formation, with upthrow on the same side and without change in the direction of dip, demands special consideration to see if it can be simply accounted for by the hypothesis here proposed.

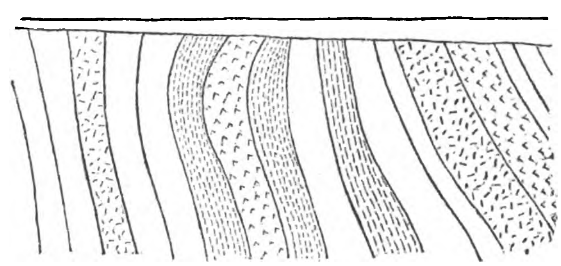


FIG. 107. Irregular curvature in the underlying slabs of schist; when straightened out by lateral compression it causes a fault in the surface beds with upthrow on the left instead of on the right, as usual, shown in Fig. 108.

The following suggestion (illustrated in Figs. 107 and 108) is offered in explanation of it: It seems admissible to assume almost any underground irregularity in the attitude of the fundamental schists, so greatly are their surface outcrops known to be contorted. Suppose, therefore, a curve introduced in the general plunge of the slabs, as

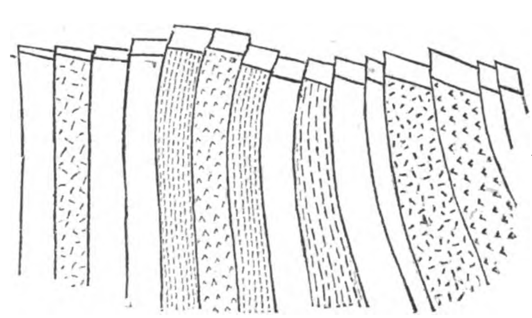


FIG. 108. Effect of irregular structure in causing a left-hand upthrow.

here represented; when the mass yields to a crushing force, the slabs in general will take a steeper position, but the local curve will flatten itself out and produce a displacement with uplift on the west, as shown in Fig. 108. Therefore, wherever the straightening of a folded slab produces an uplift on the west of a divisional plane greater than the uplift on the east that results from the general change in the

inclination of the whole series of slabs, the faults will find their upthrow on the unusual side. This relation of the two forms of distortion seems to have been rare. When the convexity of the folded slab is turned toward the dip of the future monocline, then straightening and slipping combine and the throw of the fault is locally increased. The change in the value of a fault along its strike, as required in the production of the crescentic ridges, may thus be in part produced.

The control of surface structure by dislocations in deep-lying rocks may perhaps find application in other regions than the Triassic areas. The faulted monocline of Tennessee stands greatly in need of some such explanation, and indeed, wherever unconformable masses are deformed together, reactions of the lower on the upper, such as are here suggested, should be looked for. Such a disturbance probably awaits the now horizontal Cretaceous rocks of northern France, where the sharply folded layers of the Carboniferous strata run beneath them from Belgium. Specific information concerning the process of disturbance of the Triassic rocks in the Connecticut Valley will be sought by continued investigation in the field.